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Mountain Pine Beetle Response to Different Verbenone Dosages in Pine Stands of Western Montana

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RESEARCH SUMMARY

Five dosages of verbenone, the principal anti-aggregative pheromone of mountain pine beetle (MPB) (*Dendroctonus ponderosae* Hopkins), were deployed in plastic bubble capsules in lodgepole pine (*Pinus contorta* Dougl.) and ponderosa pine (*P. ponderosa* Dougl. ex Laws.) stands in Montana to determine the optimum level of verbenone needed to prevent infestation by MPB and to determine if beetles dispersed from treated plots and increased infestation in adjacent strips. Although considerable reduction in infestation occurred in stands receiving the heaviest dosage of verbenone (compared to check stands), a statistically significant difference ($P = 0.043$) was demonstrated only for one of the two tests in lodgepole pine and for neither of the two tests in ponderosa pine. Average percentages of infested lodgepole per plot in the 1989 test ranged from 0.3 percent in the 40-capsule/acre treatment to 5.2 percent in check plots. Beetle infestation did not increase in the immediate area surrounding treatment plots.

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INTRODUCTION

Verbenone (4,6,6-trimethylbicyclo[3.1.1]-hept-3-en-2-one) was first identified as a component of the pheromone complex of the male southern pine beetle (*Dendroctonus frontalis* Zimm.) and the western pine beetle (*D. brevicomis* [LeConte]) (Renwick 1967). Subsequent field tests revealed that verbenone inhibited aggregation of both species to attractive components of their respective pheromones. In nature, these antiaggregative components are emitted following initial attack and mating. They appear to function as a mask that terminates response to the attractive elements, thereby ensuring that the density of beetle attack does not exceed the threshold for optimum brood survival (Borden and others 1987).

Verbenone was first detected in trace amounts in mountain pine beetle (MPB) (*D. ponderosae* Hopkins) by Pitman and others (1969) in hindguts of emergent and feeding female MPB, and later from air surrounding emergent male/female pairs (Rudinsky and others 1974). Other sources of verbenone are auto-oxidation of alpha-pinene from resin and microorganisms (primarily yeasts) growing in beetle galleries (Hunt and Borden 1989). Subsequent laboratory and field bioassays conducted in Oregon confirmed that verbenone also served as an antiaggregative component of the MPB pheromone complex (Ryker and Yandell 1983). When verbenone was released in funnel traps in British Columbia at 1 or 5 mg/24 hours in the presence of the attractive synthetic MPB lure (*trans*-Verbenol, *exo*-Brevicomin, and myrcene), male response was reduced by approximately 75 percent. Female response followed a similar, although not statistically significant, trend (Borden and others 1987). Similarly, in Utah, when verbenone was added to funnel traps baited with the same MPB lure, the catch of MPB was reduced 98 percent when compared to the catch in traps with the lure alone (Schmitz and McGregor 1990). Electroantennograms obtained for the MPB to selected pheromones revealed significant differences in response between males and females exposed to the highest elution rate (Whitehead and others 1989).

Verification of the antiaggregative properties of verbenone, and the need for environmentally acceptable suppression strategies to limit tree losses to MPB, prompted a series of field tests to determine the effectiveness of verbenone in preventing infestation of high-hazard pine stands. During 1987, verbenone packaged in clear plastic bubble capsules was field tested at the rate of 100 capsules per acre in lodgepole pine stands (*Pinus contorta* Dougl.) in Idaho and British Columbia (Amman and others 1989; Lindgren and others 1989). Both tests demonstrated that verbenone reduced MPB infestations not only in ordinary stands but also in stands baited with a lure to ensure the presence of MPB. These findings led to further tests designed to determine the most effective dosage (numbers of capsules per acre) in both lodgepole and ponderosa pines (*Pinus ponderosa* Dougl. ex Laws.). Simultaneous field tests were conducted in Idaho (Amman and others, in press), Colorado and South Dakota (Bentz and others 1989), South Dakota (Lister and others 1990), and Montana, the results from Montana being reported herein.

The objectives of the studies were to (1) determine the most effective dosage of verbenone capsules per acre, and (2) determine if a reduction in MPB infestations in the verbenone-treated stands resulted in increased infestations in stands immediately surrounding the treated areas.

STUDY AREA

The study area in lodgepole pine in 1988 was located on the Flathead National Forest, at an elevation of 5,600 feet above sea level. Lodgepole pine 5 inches and larger diameter at breast height

(d.b.h.) averaged 8.5 inches d.b.h. and 80 years old. Species composition within the stands averaged 95 percent lodgepole pine, with the remainder being mostly subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.), Engelmann spruce (*Picea engelmannii* Parry), and western larch (*Larix occidentalis* Nutt.).

The study area in ponderosa pine in 1988 was located on the Kootenai National Forest, at an elevation of 3,600 feet above sea level. Ponderosa pine 5 inches and larger d.b.h. averaged 9.3 inches d.b.h. and were 32 years old (most were plantations artificially regenerated in 1956). Species composition within the stands averaged 80 percent ponderosa pine. The remainder was mostly Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) and western larch.

In 1989, the study area in lodgepole pine was on the Lolo National Forest, at an elevation ranging from 5,400 to 5,600 feet. Stands were 90 percent lodgepole pine, with the remainder being subalpine fir, Douglas-fir, and western larch. Lodgepole pine 5 inches d.b.h. and larger averaged 8.2 inches d.b.h.; ages varied from 90 to 100 years.

The 1989 study area in ponderosa pine was located in stands on State and private lands south of Darby, MT, at an elevation of approximately 4,800 feet. The average diameter of ponderosa pine 5 inches d.b.h. and larger was 8.7 inches. Species composition was 88 percent ponderosa pine and the remainder Douglas-fir. Second-growth stands were 50 to 80 years old, and remnant old-growth ponderosa pine exceeded 200 years.

METHODS

In 1988, a randomized block design, replicated four times in each pine host, was used to test five densities of verbenone capsules (verbenone released at the rate of 5 mg/capsule/24 hours at 25 °C). Densities of verbenone capsules were 0, 10, 20, 40, and 68 per acre, spaced in a grid pattern within the treated plots. Each block consisted of five 2.5-acre plots that were located 5 chains apart (1 chain = 66 feet).

Treatments were randomly assigned to the five plots comprising a block. This random assignment of treatments then was repeated in each block to ensure that any given treatment was not adjacent to the same treatment in an adjoining block.

Verbenone capsules obtained from Phero Tech Inc., Delta, BC, Canada, were constructed of a clear plastic bubble with a clear plastic membrane. A cardboard was attached to shade the surface exposed to the sun (fig. 1). Each capsule contained 0.5 g of verbenone (chemical purity of 98.6 percent and an optical purity of –72 percent). The capsules were stapled to the north sides of trees, 6 to 7 feet above ground.

In 1989, the dosage-response portion of the study (objective 1) was repeated, with the following changes:

1. Treatments were replicated eight times instead of four.
2. A newly designed capsule differed from previous models by use of opaque plastic on the surface exposed to the sun, rather than clear plastic with

Figure 1—Plastic bubble capsule used to deploy verbenone.

a cardboard shade. Each capsule contained 0.8 g of verbenone.

3. Treatments were randomized within each block instead of repeating the same order in all blocks.

4. MPB infestation was not evaluated in strips adjacent to treated plots.

Treatments were applied June 16 and 17 in lodgepole pine, and June 14 and 15 in ponderosa pine in 1988. Treatments were applied June 21 and 22 in lodgepole pine, and June 19 to 28 in ponderosa pine in 1989. Treatment effects were assessed September 6 to 13 in 1988, and September 18 to 20 in 1989, after beetles had flown. A 100 percent survey of each plot was made to measure the diameter at breast height of all pines 5 inches and larger d.b.h. and to determine tree mortality by MPB for each year—1987, 1988, and 1989. Treatment effects were evaluated by the percentage of pines that were mass-attacked by MPB following verbenone treatment. Percentages of infested trees were transformed to arcsin. Randomized complete block ANOVA was used to test for significant treatment effects. Multiple-comparison procedures, such as Duncan's, cannot be applied properly to a structured experiment of this type (Warren 1986). The question of importance, however, is not pairwise differences between treatments, but rather the change in beetle response to different verbenone levels.

To assess the possible attractiveness of MPB to verbenone in stands adjacent to 1988 treatments, two 1-chain-wide strips (66 feet) were established around each plot (fig. 2), and all trees infested in 1987 and 1988 were counted and tallied separately for each strip. Numbers of 1988-infested trees in each strip were analyzed separately by randomized complete block ANOVA. Numbers per acre, rather than percentages of infested trees, were used in order to save inventorying all surviving trees in the strips for percentage calculations.

RESULTS AND DISCUSSION

Treatment Effects in Lodgepole Pine

In 1988, statistically significant differences in percentages of newly infested trees did not occur among either blocks (P= 0.30) or treatments

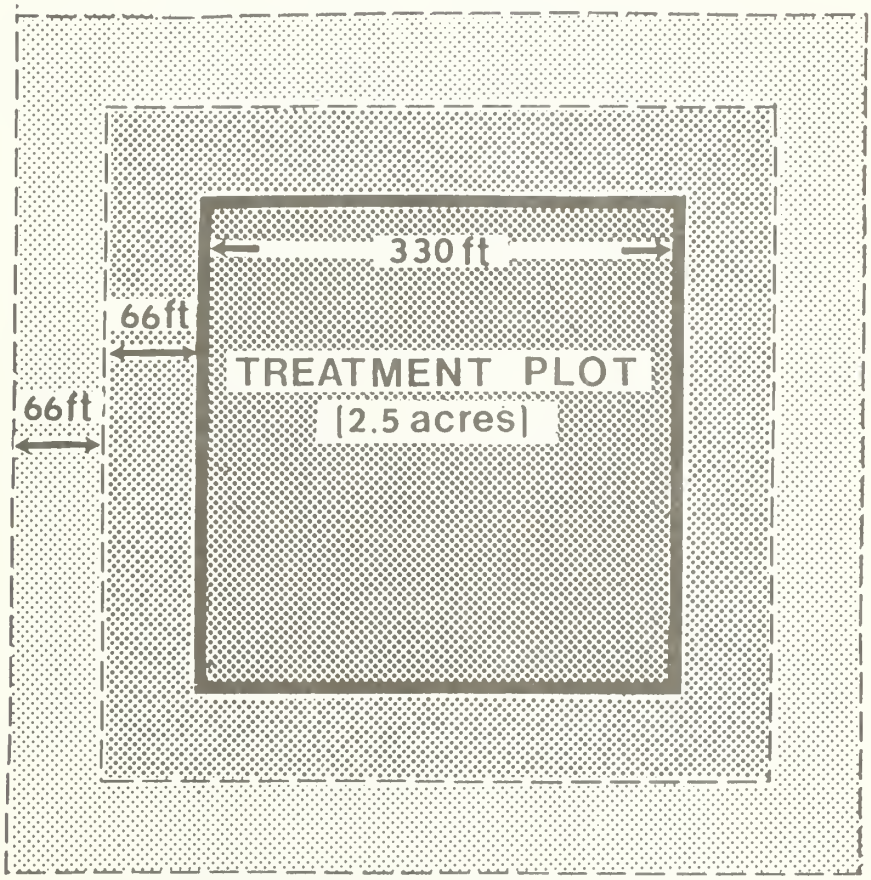

Figure 2—Design of verbenone treatment plot and surrounding strips used in the 1988 tests.

($F = 1.64$; df = 4, 12; $P = 0.23$). Average tree losses, however, show substantial declines in some treatments, particularly the 68-capsule/acre treatment (fig. 3). Average percentages of infested trees per plot ranged between zero for the 20- and 68-capsule/acre treatments, and 0.4 for check plots (table 1). The population level of MPB probably was too low to adequately test the treatments.

In 1989, statistically significant differences in percentages of newly infested trees did not occur among blocks ($P = 0.247$), but did occur among treatments ($P = 0.043$) (table 2). Check plots had higher percentages of infested trees ($\bar{x} = 5.2$ percent) than the verbenone-treated plots (means ranged from 0.3 percent for the 40-capsule/acre treatment and 0.8 percent for the 10- and 68-capsule/acre treatments (table 3). Percentage of infested trees declined with increasing numbers of verbenone capsules up to 40 per acre, then increased at 68 per acre. The effect of verbenone on numbers of infested lodgepole (fig. 4) is similar to that for verbenone tests in lodgepole pine of central Idaho (Amman and others, in press). The increase in infestation in the 68-capsule/acre treatment in this test and both of the central Idaho tests (Amman and others, in press) suggests some altering of beetle behavior at the high verbenone dosage. This may be similar to infestation behavior toward the end of an infestation, when many trees in a stand are infested and natural verbenone levels should be at their highest level. Under these conditions, beetles appear to be less selective in tree choice, infesting many small-diameter trees even though these are marginal for beetle production (Cole and Amman 1980).

Numbers of infested trees from which beetles emerged to infest trees following verbenone treatment, and numbers of green trees available for infestation, were analyzed to determine if they may have affected results. In the 1988 test, the number of 1987 infested lodgepole did not differ significantly among treatments ($F = 1.78$; df = 4, 12; $P = 0.20$), but the number of green lodgepole did ($F = 3.59$; df = 4, 12; $P = 0.04$). Average numbers of 1987 infested trees per acre ranged from 8.4 in the 68-capsule/acre treatment to 0.5 in the 20-capsule/acre treatment (table 1). Average numbers of green trees per acre ranged from 220 in the 40-capsule/acre treatment to 391 in the 10-capsule/acre treatment. It is doubtful that the difference in numbers of green lodgepole among treatments had a significant effect on results. The low numbers of infested trees in 1987 was probably the overriding factor precluding a satisfactory test of verbenone.

In the 1989 test, the number of 1988 infested lodgepole did not differ significantly among treatments ($F = 0.32$; df = 4, 28; $P = 0.86$). Mean numbers of infested lodgepole per acre ranged from 6.2 in the 40-capsule treatment to 13.4 in the 68-capsule/acre treatment (table 3). Numbers of green lodgepole also did not differ among treatments ($F = 0.99$; df = 4, 28; $P = 0.43$). Mean numbers of green lodgepole pine per acre ranged from 327 in the 68-capsule/acre treatment to 227 in the check plots (table 3).

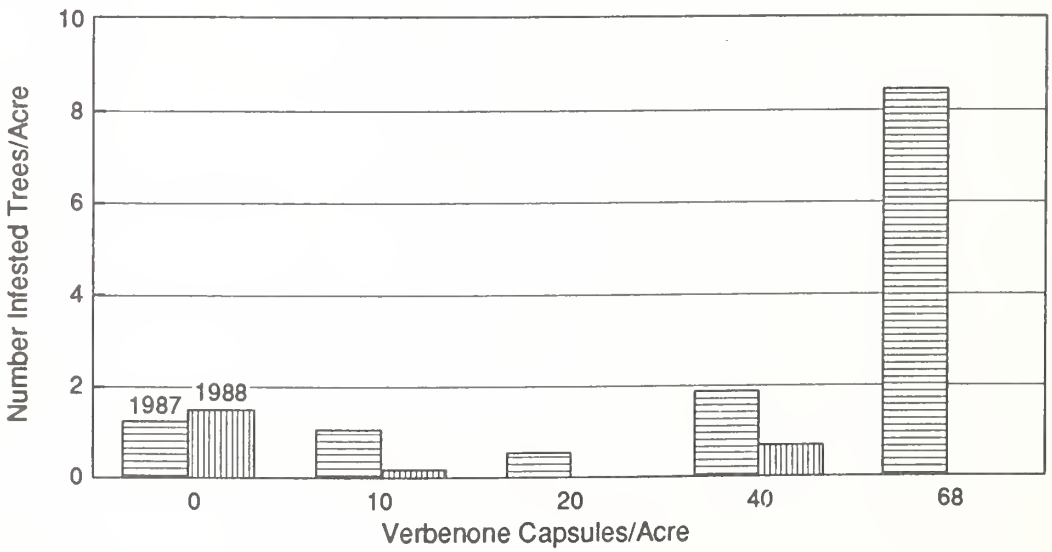

Figure 3—Numbers of lodgepole pine trees 5 inches and larger d.b.h. infested by MPB in plots in 1987, prior to treatment, and in 1988 following treatment with different numbers of verbenone bubble capsules, Flathead National Forest, MT.

Table 1—Number of mountain pine beetle infested and uninfested lodgepole pines per acre in verbenone-treated plots and in surrounding strips, Flathead National Forest, MT, 1988

Treatment[1]	Uninfested trees[2]		Treated plot								First 66-foot-wide strip						Second 66-foot-wide strip					
			Trees infested						Ratio		Trees infested				Ratio		Trees infested				Ratio	
			1987[3]			1988			1988/1987		1987		1988		1988/1987		1987		1988		1988/1987	
	$\bar{x}$	*sd*	$\bar{x}$	*Pct*[4]	*sd*	$\bar{x}$	*Pct*	*sd*	$\bar{x}$	*sd*	$\bar{x}$	*sd*	$\bar{x}$	*sd*	$\bar{x}$	*sd*	$\bar{x}$	*sd*	$\bar{x}$	*sd*	$\bar{x}$	*sd*
Check	381	59.0	[5]1.2	0.3	2.1	1.4	0.4	1.6	4.27	5.27	1.5	2.4	1.4	1.6	0.21	0.29	1.6	1.9	1.1	1.3	0.63	0.71
10	391	36.0	1.0	.3	1.7	.1	<.1	.2	.50	.71	.3	.6	0	0	0	0	.5	.5	.3	.4	.67	.47
20	318	76.5	.5	.2	1.0	0	0	0	0	0	.9	1.9	.1	.2	.11	—	1.3	2.5	.2	.3	.13	—
40	220	77.1	1.8	.8	3.1	.6	.3	1.2	.19	.27	1.5	1.4	1.0	1.4	.71	.92	1.1	.8	2.3	3.2	2.25	2.84
68	334	90.7	8.4	2.5	11.5	0	0	0	0	0	.4	.8	1.1	1.8	.50	—	1.7	1.7	1.1	1.5	1.08	1.01

[1]Number of verbenone capsules per acre.
[2]Live trees 5 inches and larger d.b.h. available for infestation when plots were treated with verbenone.
[3]Number of infested trees providing beetles to infest trees following verbenone application.
[4]Percentages of trees infested by MPB.
[5]Statistics based on four replicates.

Table 2—Randomized block ANOVA statistics for percentages (arcsin transformation) of lodgepole pine infested by MPB in plots treated with different dosages of verbenone, Lolo National Forest, MT, 1989

Source	df	Mean sum of squares	*F* ratio	*P*
Block	7	1.0795	1.39	0.247
Treatment	4	2.1995	2.84	.043
Error	28	.7751		

Table 3—Number of mountain pine beetle infested and uninfested lodgepole pines per acre in verbenone-treated plots, Lolo National Forest, MT, 1989

Treatment[1]	Uninfested trees[2]		Infested trees							
			1988[3]			1989			Ratio 1989/1988	
	$\bar{x}$	*sd*	$\bar{x}$	*Pct*[4]	*sd*	$\bar{x}$	*Pct*	*sd*	$\bar{x}$	*sd*
Check	[5]227	106.7	12.8	5.3	17.9	11.8	5.2	18.6	4.83	12.03
10	271	111.6	10.0	3.6	14.1	2.1	.8	2.1	.77	1.04
20	251	118.8	9.7	3.7	10.2	1.3	.5	2.6	.08	.15
40	295	132.7	6.2	2.1	9.2	.8	.3	1.5	.05	.07
68	327	120.4	13.4	3.9	16.4	2.6	.8	3.5	.27	.65

[1]Number of verbenone capsules per acre.
[2]Live trees 5 inches and larger d.b.h. available for infestation when plots were treated with verbenone.
[3]Number of infested trees providing beetles to infest trees following verbenone application.
[4]Percentages of trees infested by MPB.
[5]Statistics based on eight replicates.

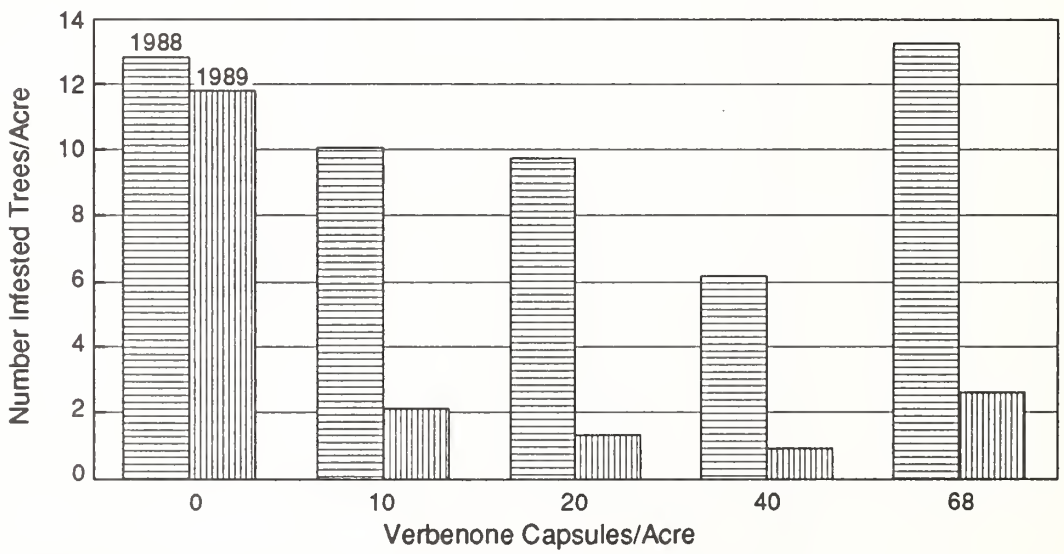

Figure 4—Numbers of lodgepole pine trees 5 inches and larger d.b.h. infested by MPB in plots in 1988, prior to treatment, and in 1989 following treatment with different numbers of verbenone bubble capsules, Lolo National Forest, MT.

Treatment Effects in Ponderosa Pine

A statistically significant effect in percentages of newly infested trees was not evident among the blocks ($P = 0.30$) nor among the treatments ($F = 2.27$; df = 4, 12; $P = 0.12$) in 1988. Mean percentages of infested trees ranged from 0.9 per plot in the 68-capsule/acre treatment to 12.6 in the 20-capsule/acre treatment (table 4).

A statistically significant difference occurred among blocks ($P = 0.028$) but not among verbenone treatments in the 1989 test ($F = 1.50$; df = 4, 28; $P = 0.23$). Mean percentages of MPB-infested trees ranged from 0.6 per acre in the 68-capsule/acre treatment to 2.8 per acre in check plots (table 5). The significant difference among blocks does not invalidate the test, but rather indicates that the precision of the experiment has been increased by use of the randomized block design instead of a completely random design (Steel and Torrie 1960).

Two factors that could have affected the results were the numbers of infested trees from which beetles emerged to infest trees following verbenone treatment, and numbers of green trees available for infestation. In the 1988 test, however, the number of 1987 infested ponderosa did not differ significantly among treatments ($F = 1.18$; df = 4, 12; $P = 0.36$), nor did the number of green trees differ ($F = 1.73$; df = 4, 12; $P = 0.21$). Average numbers of 1987 infested ponderosa ranged from 2.3 per acre in the 40-capsule/acre treatment to 15.2 per acre in the 10-capsule/acre treatment (fig. 5). Average numbers of green ponderosa ranged from 66 per acre in the 20-capsule/acre treatment to 103 per acre in the check and 68-capsule/acre treatment. In the 1989 test, the number of 1988 infested ponderosa did not differ significantly ($F = 0.32$; df = 4, 28; $P = 0.86$). Mean numbers of infested ponderosa ranged from 16.2 per acre for the 68-capsule/acre treatment to 18.4 per acre for the 10-capsule/acre treatment (table 5) (fig. 6). Numbers of green ponderosa available for infestation also did not differ among treatments ($F = 1.46$; df = 4, 28; $P = 0.24$). Mean numbers of green ponderosa pine ranged from 157 per acre for check stands to 214 per acre for the 20-capsule/acre treatment. The lack of significance in numbers of infested trees prior to verbenone treatment and numbers of green trees available for infestation suggests these variables did not influence results of tests in ponderosa pine stands.

The failure of MPB to infest ponderosa in some check plots following verbenone treatment, even though infested trees were in the plots prior to verbenone treatments, appears to have influenced results. The zero counts greatly increased variance and precluded demonstration of any treatment effect when checks were compared with verbenone-treated plots. The behavior of the MPB appears to differ somewhat between lodgepole and ponderosa pine at the levels of infestation observed in these tests. In lodgepole pine, the MPB infestation expands from initial spots, whereas in ponderosa pine, MPB is more likely to move from one spot and create another, killing trees in groups (McCambridge and Trostle 1970). Therefore, because of this fundamental difference in MPB behavior, demonstration of a significant treatment effect may be more difficult in ponderosa than lodgepole pine. Biologically, the results look quite significant, with numbers of infested trees averaging 1.03 per acre for the 68-capsule/acre treatment, compared to 7.0 per acre for checks for the 1988 and 1989 tests combined. Bentz and others (1989) also were unable to demonstrate a significant treatment effect in ponderosa pine stands in Colorado, probably because MPB populations were very large, infesting an average of more than 150 trees per plot. In South Dakota, however, a strong trend was apparent, with numbers of infested trees decreasing with increasing verbenone dosage (Bentz and others 1989). The 1989 tests in South Dakota also showed a strong decline in infested trees with increased verbenone (Lister and others 1990). The low amount of verbenone elution in 1989 may have contributed to lack of a significant treatment effect (Lister and others 1990). Another difference between results from ponderosa and lodgepole is that infestation increased in the 68-capsule/acre treatment, compared to 40-capsule/acre treatment, in lodgepole but not in ponderosa. Whether this difference is inherent or due to physical differences between lodgepole and ponderosa pine stands is unknown. Lodgepole stands, however, are denser than ponderosa stands and may hold more of the verbenone in the stand, whereas the more open ponderosa stands may allow greater air circulation and movement of verbenone out of the stand. The effect of stand density in pheromone communication by MPB was discussed by Schmitz and others (1989).

Verbenone Effect in Adjacent Strips

The low amount of MPB activity in lodgepole pine in 1988 precluded obtaining a meaningful evaluation of whether MPB dispersed from verbenone-treated plots and infested trees in adjacent strips (table 1). Nevertheless, infestation level was high enough in ponderosa pine to test this objective adequately.

Numbers of 1988 infested ponderosa pine in the first 1-chain-wide strip around verbenone-treated plots were not different from those inside the plots ($F = 0.28$; df = 4, 12; $P = 0.88$). Mean numbers of infested trees ranged from 1.0 per acre around the

Table 4—Number of mountain pine beetle infested and uninfested ponderosa pines per acre in verbenone-treated plots and in surrounding strips, Kootenai National Forest, MT, 1988

Treatment[1]	Uninfested trees[2]		Treated plot								First 66-foot-wide strip						Second 66-foot-wide strip					
			Trees infested						Ratio		Trees infested				Ratio		Trees infested				Ratio	
			1987[3]			1988			1988/1987		1987		1988		1988/1987		1987		1988		1988/1987	
	$\bar{x}$	*sd*	$\bar{x}$	*Pct*[4]	*sd*	$\bar{x}$	*Pct*	*sd*	$\bar{x}$	*sd*	$\bar{x}$	*sd*	$\bar{x}$	*sd*	$\bar{x}$	*sd*	$\bar{x}$	*sd*	$\bar{x}$	*sd*	$\bar{x}$	*sd*
Check	103	17.0	[5]8.4	7.5	9.9	12.2	11.8	13.6	27.29	46.52	9.2	5.4	12.4	8.3	1.85	1.32	14.6	4.4	14.2	2.8	1.02	0.32
10	81	19.2	15.2	15.8	11.9	2.4	3.0	1.1	.13	.09	13.3	10.4	1.0	1.0	.07	.07	6.3	4.9	2.2	2.2	.39	.49
20	66	7.4	10.1	13.3	13.2	8.3	12.6	10.4	1.03	1.01	16.1	12.7	11.5	9.0	.55	.48	8.4	3.0	4.9	5.7	.51	.59
40	96	25.6	2.3	2.3	3.2	4.5	4.7	3.2	1.22	.40	11.7	11.0	5.6	2.9	2.15	3.26	6.5	6.2	2.4	2.2	.40	.43
68	103	39.3	3.9	3.6	4.8	.9	.9	1.3	.04	.05	10.5	9.7	4.4	5.8	.82	1.35	6.3	5.3	3.4	4.4	.45	.40

[1]Number of verbenone capsules per acre.
[2]Live trees 5 inches and larger d.b.h. available for infestation when plots were treated with verbenone.
[3]Number of infested trees providing beetles to infest trees following verbenone application.
[4]Percentages of trees infested by MPB.
[5]Statistics based on four replicates.

Table 5—Number of mountain pine beetle infested and uninfested ponderosa pines per acre in verbenone-treated plots, Bitterroot National Forest, MT, 1989

Treatment[1]	Uninfested trees[2]		Infested trees							
			1988[3]			1989			Ratio 1989/1988	
	$\bar{x}$	*sd*	$\bar{x}$	*Pct*[4]	*sd*	$\bar{x}$	*Pct*	*sd*	$\bar{x}$	*sd*
Check	[5]157	51.7	17.9	10.2	19.9	4.4	2.8	6.2	0.27	0.24
10	184	41.3	18.4	9.1	17.9	3.8	2.1	3.7	.38	.33
20	214	93.4	17.4	7.5	7.7	2.5	1.2	1.6	.21	.30
40	208	60.4	16.7	7.4	9.1	3.0	1.4	3.7	.21	.29
68	177	51.4	16.2	8.4	8.8	1.0	.6	1.0	.09	.11

[1]Number of verbenone capsules per acre.
[2]Live trees 5 inches and larger d.b.h. available for infestation when plots were treated with verbenone.
[3]Number of infested trees providing beetles to infest trees following verbenone application.
[4]Percentages of trees in the stand infested by MPB.
[5]Statistics based on eight replicates.

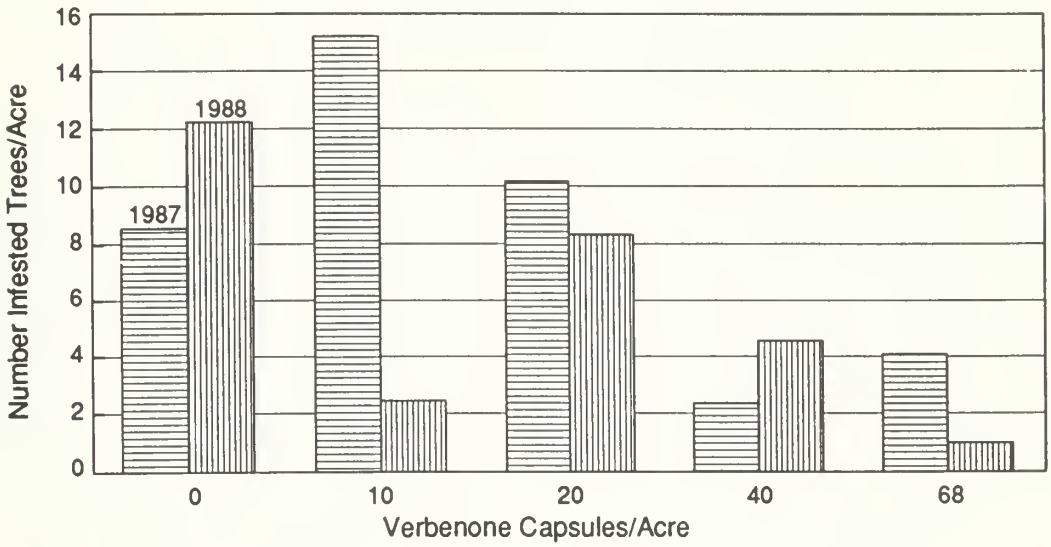

Figure 5—Numbers of ponderosa pine trees 5 inches and larger d.b.h. infested by MPB in plots in 1987, prior to treatment, and in 1988, following treatment with different numbers of verbenone bubble capsules, Kootenai National Forest, MT.

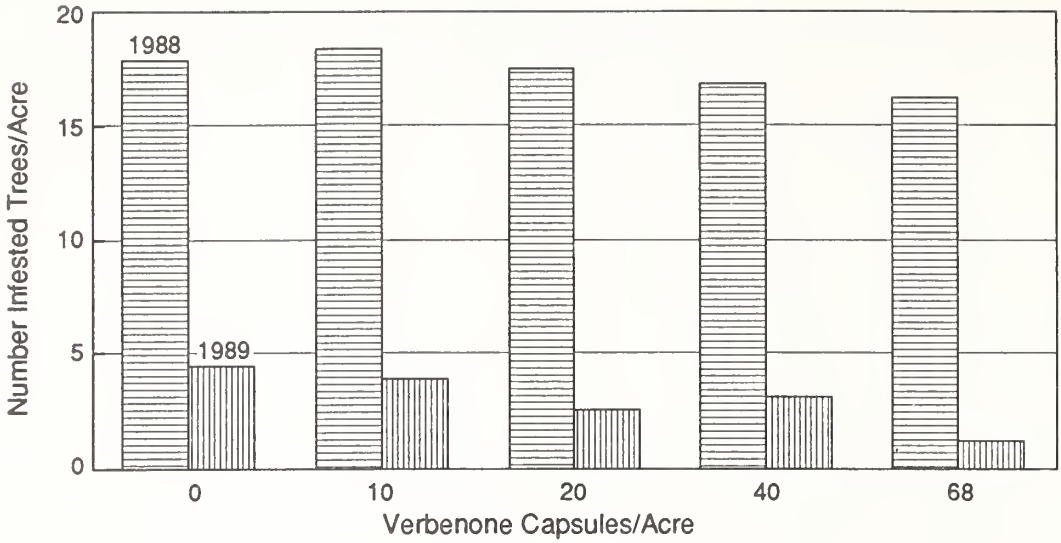

Figure 6—Numbers of ponderosa pine trees 5 inches and larger d.b.h. infested by MPB in plots in 1988, prior to treatment, and in 1989, following treatment with different numbers of verbenone bubble capsules, Montana State Lands.

10-capsule/acre treatment to 12.4 per acre around check plots (table 4). Neither was a significant difference detected in numbers of 1988-infested trees in the second 1-chain-wide strip around the plots ($F = 0.50$; df = 4, 12; $P = 0.73$). Mean numbers of infested trees ranged between 2.2 per acre around the 10-capsule/acre treatment and 14.2 per acre around check plots. This lack of significance suggests that MPB infestation at population levels we encountered is not increased around treated plots. We expected beetles dispersed from the plots to infest trees somewhere outside the plots, and most likely within 2 chains of the treated plot. Reduced infestation in the strips surrounding ponderosa pine plots, although not significant, suggests that the suppressing effect of verbenone could be extending beyond the treated plots. In lodgepole pine tests in central Idaho, a significant increase in infestation within the surrounding 2-chain-wide strips also was not detected (Amman and others, in press). The reduced amount of MPB infestation around the heaviest treatment (68 capsules/acre) in Idaho also suggests that the effect of verbenone extended beyond the plots and suppressed beetle activity in the surrounding strips.

CONCLUSIONS

Verbenone significantly reduced MPB infestation in one of two tests in lodgepole pine stands, but not in ponderosa pine stands. MPB infestation does not increase significantly in strips adjacent to treated plots.

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In 1988 and 1989, five dosages of verbenone, principal antiaggregative pheromone of mountain pine beetle (MPB) (*Dendroctonus ponderosae* Hopkins), were deployed in plastic capsules in lodgepole pine (*Pinus contorta* Dougl.) and ponderosa pine (*P. ponderosa* Dougl. ex Laws.) stands in Montana. Objectives were to determine optimum dosage needed to prevent MPB infestation and to determine if beetles dispersed to trees adjacent to treated plots. In treated stands a statistically significant ($P = 0.043$) reduction in infestation was demonstrated only for the 1989 test in lodgepole pine and for neither of the two tests in ponderosa pine. In the 1989 test infested lodgepole ranged from 0.3 percent in the 40-capsule/acre treatment to 5.2 percent in check plots.

KEYWORDS: *Dendroctonus ponderosae, Pinus contorta, Pinus ponderosa*, pheromone, pest control, antiaggregative agent

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